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Revision 0

Criticality Curves for Plutonium Hydraulic Fluid Mixtures

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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Richland, Washington

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Criticality Curves for Plutonium Hydraulic Fluid Mixtures

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W. D. Wittekind
Fluor Hanford, Inc.

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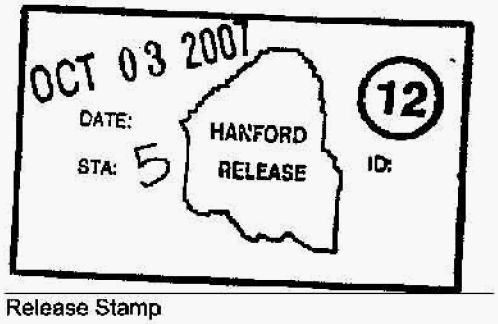

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Calculation Cover Sheet and Revision Summary

Section 1: Identification

1. Project Identifier	2. Modification Description Title/Subject	3. Page 1 ~~of 46~~ 2DW
PFP	Criticality Curves for Plutonium Hydraulic Fluid Mixtures	

4. Use of Form

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List of Terms

D&D	decontamination and decommissioning
g Pu	grams of plutonium
MCNP	Monte Carlo N-Particle
PFP	Plutonium Finishing Plant
PRF	Plutonium Reclamation Facility
RMA	Remote Mechanical A-line
SWB	Standard Waste Box

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1.0 PURPOSE

This Calculation Note performs and documents MCNP criticality calculations for plutonium (100% ^{239}Pu) hydraulic fluid mixtures. Spherical geometry was used for these generalized criticality safety calculations and three geometries of neutron reflection are:

- bare,
- 1 inch of hydraulic fluid, or
- 12 inches of hydraulic fluid.

This document shows the critical volume and critical mass for various concentrations of plutonium in hydraulic fluid. Between 1 and 2 gallons of hydraulic fluid were discovered in the bottom of HA-23S. This HA-23S hydraulic fluid was reported by engineering to be Fyrquel® 220. The hydraulic fluid in Glovebox HA-23S is Fyrquel® 220 which contains phosphorus. Critical spherical geometry in air is calculated with 0 in., 1 in., or 12 inches hydraulic fluid reflection.

This document fulfills the requirements of HNF-PRO-8259 *PHMC Calculation Preparation and Issue (Including OCRWM)* (FH 2007) regarding the documentation of calculations.

These plutonium hydraulic fluid mixture critical curves are intended for guidance and application to any operation where plutonium may be mixed with hydraulic fluid. The expected operation is to remove the hydraulic fluid, with an unknown amount of plutonium contamination in containers that may then be moved into a temporary waste container and then into a 55 gallon drum or into a Standard Waste Box (SWB). The hydraulic fluid or unknown oily substances may be encountered as various systems are disassembled during D&D (e.g., the 26 in. vacuum system, the E-4 system, PRF Gallery Gloveboxes, transfer lines, remaining vessels and piping in the RMA line, etc.) – this material will require safe handling, and the handbook capability must be expanded from water and nitric acid to Fyrquel® 220 and to other oily substances.

Glovebox HA-23S is rectangular in shape with approximate outside dimensions as follows: 189 inches long, 48 inches wide and 138 inches high. The bottom of the glovebox is raised on legs approximately 10 inches above the concrete floor. The glovebox is divided vertically into four levels, separated by expanded steel mesh floors (which may be removed during the course of the operation). Each level contains a conveyor that was previously used for storing fissionable material containers. The conveyors are approximately 34 inches apart vertically. Each conveyor is shaped like a racetrack; the straight-aways are approximately 123 inches long.

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Moveable 10-inch thick water walls surround one end and two sides of the glovebox. The water walls are normally full; however they may be empty or removed all together during the course of the operation. The south end of the glovebox abuts the HA-28 conveyor glovebox and contains a four level hydraulic pallet lift and personnel elevator access area. Loading and unloading of pallets and equipment access is normally performed on the second level, which has the HA-28 access bay. Items and equipment are moved between levels on a hydraulic lift inside the glovebox.

Glovebox HA-23S was observed to have a collection of fluid in the bottom. The fluid was about six feet long, four feet wide and may have been between $^1/_8$ inch and ¼ inch thick at the deep end. Assuming wedge geometry, the volume calculated out to between one gallon and two gallons volume.

The plutonium was modeled as 100 wt% ^{239}Pu. This composition will bound all reactor produced plutonium which has greater ^{240}Pu content than the ^{241}Pu content.

2.0 SUMMARY OF RESULTS

The critical mass of plutonium in hydraulic fluid is greater than the critical mass of plutonium in water. This means that criticality safety can conservatively use the plutonium water critical curves when setting criticality safety limits when dealing with hydraulic fluids.

3.0 ASSUMPTIONS

1. Assumes 100 wt% ^{239}Pu in the plutonium.
2. Average hydraulic fluid mixture of components is given in MSDS# 014029 revision 3 (dated 04/24/2007)
3. Hydraulic fluid density is 1.17 g/cm^3, maximum from MSDS# 014029 revision 3 (dated 04/24/2007).
4. Geometry is conservatively analyzed as a sphere.
5. Reflectors are modeled as uniform shells of hydraulic fluid.
6. Plutonium is uniformly distributed throughout the hydraulic fluid.

4.0 SOFTWARE APPLICATIONS, DESCRIPTIONS, INSTALLATION & CHECKOUT, AND STATEMENTS OF VALIDITY

4.1 HANDBOOK REFERENCES

Criticality handbooks, such as ARH-600 (Carter et al. 1968) with their figures are standard ways of communicating the criticality safety parameters of concern. Criticality handbooks have been used for a number of years and have been compared to other computer

computations by a number of criticality safety engineers in the course of validating or using the figures for criticality safety purposes.

4.2 CRITICALITY SAFETY LIMIT

The double contingency principle states that a nuclear process must have sufficient factors of safety in the operation so that at least two unlikely, independent, and concurrent changes in the process conditions are required before a criticality accident is possible. An "unlikely" change in conditions is defined as an upset having a probability of ≤ 0.01 per year. Such an unlikely upset is also called a contingency.

A nuclear criticality requires a neutron multiplication factor (k_{eff}) of unity, i.e., $k_{eff} = 1.0$. Due to uncertainties, the k_{eff} value for the point at which a criticality is considered "possible" includes a safety margin of $\Delta k_{eff} = 0.05$. It also must include the average bias in the computer code (MCNP 4C) as determined by comparison of calculations with experiments, the uncertainty in that average bias, and the statistical uncertainty of the MCNP 4C calculations. The code validation summarized in Appendix B for MCNP 4C results in a k_{eff} limit of either 0.943 for a system of non-metal (including oxides) plutonium material, or 0.933 for plutonium metal systems. These values for the criticality safety limit are derived using 0.001 as the upper limit for the statistical uncertainty obtained in the MCNP calculations.

This analysis did not incorporate the 0.05 safety margin, or the MCNP code bias. When these results are used in a criticality safety application, care should be used to include the 0.05 safety margin and the MCNP code bias.

5.0 CALCULATION

Evaluation considers fissionable material in spheres with three different degrees of neutron reflection, bare, 1 inch hydraulic fluid, and 12 inches hydraulic fluid. The hydraulic fluid is Fyrquel® 220, which is a butylated triphenyl phosphate mixture. $C_{20.22}H_{21.75}O_4P$ was used for the average chemical composition at a density of 1.17 g/cm^3. The hydraulic fluid mixture information is more completely assembled in Appendix D, *MCNP Computer Modeling*. The plutonium was modeled as plutonium metal at 19.6 g/cm^3. Plutonium metal is considered to be conservative compared to the PuO_2 that would realistically be expected to be found. The ^{239}Pu-$C_{20.22}H_{21.75}O_4P$ mixture was modeled with different plutonium densities with the $C_{20.22}H_{21.75}O_4P$ filling the void volume.

The analysis used the $C_{20.22}H_{21.75}O_4P$ formula. There were various plutonium densities between 19.60 g/cm^3 and 0.002 g Pu/cm^3. A range of plutonium masses was calculated at all three neutron reflection conditions. The range of plutonium masses covered the subcritical and supercritical sides of the reactivity curve for all three neutron reflection conditions.

Handbook references did not include hydraulic fluid moderation or neutron reflection, and are being extended by MCNP calculations in this calculation note.

Plutonium composition is assumed to be 0 wt% ^{240}Pu (100 wt% ^{239}Pu). There is a very limited availability of low wt% ^{240}Pu material (Crowe and Szempruch 1994).

6.0 RESULTS/CONCLUSIONS

Critical curves of mass versus volume for plutonium in Fyrquel® 220 hydraulic fluid are presented in Figure 6-1, *Critical Curves for Hydraulic Fluid*.

MCNP calculations showing the MCNP Plutonium mass and volume for each Plutonium density in the sphere, or degree of moderation, are shown in Figure 6-2, *MCNP Complete Curves for Hydraulic Fluid*.

The MCNP calculated k_{eff} are calculated at 10 different mass/volume sphere sizes, and then the k_{eff}'s were used to interpolate to $k_{eff} = 1.00$ for each plutonium density and for the three reflector models (bare, 1 inch hydraulic fluid, and 12 inches hydraulic fluid). These complete MCNP curves for hydraulic fluid are also tabulated in Table 6-1, *Hydraulic Fluid Critical Curve Interpolated MCNP Calculated Results*.

The MCNP calculated minimum critical mass for Plutonium mixed in hydraulic fluid is greater than the MCNP calculated minimum critical mass for Plutonium mixed in water.

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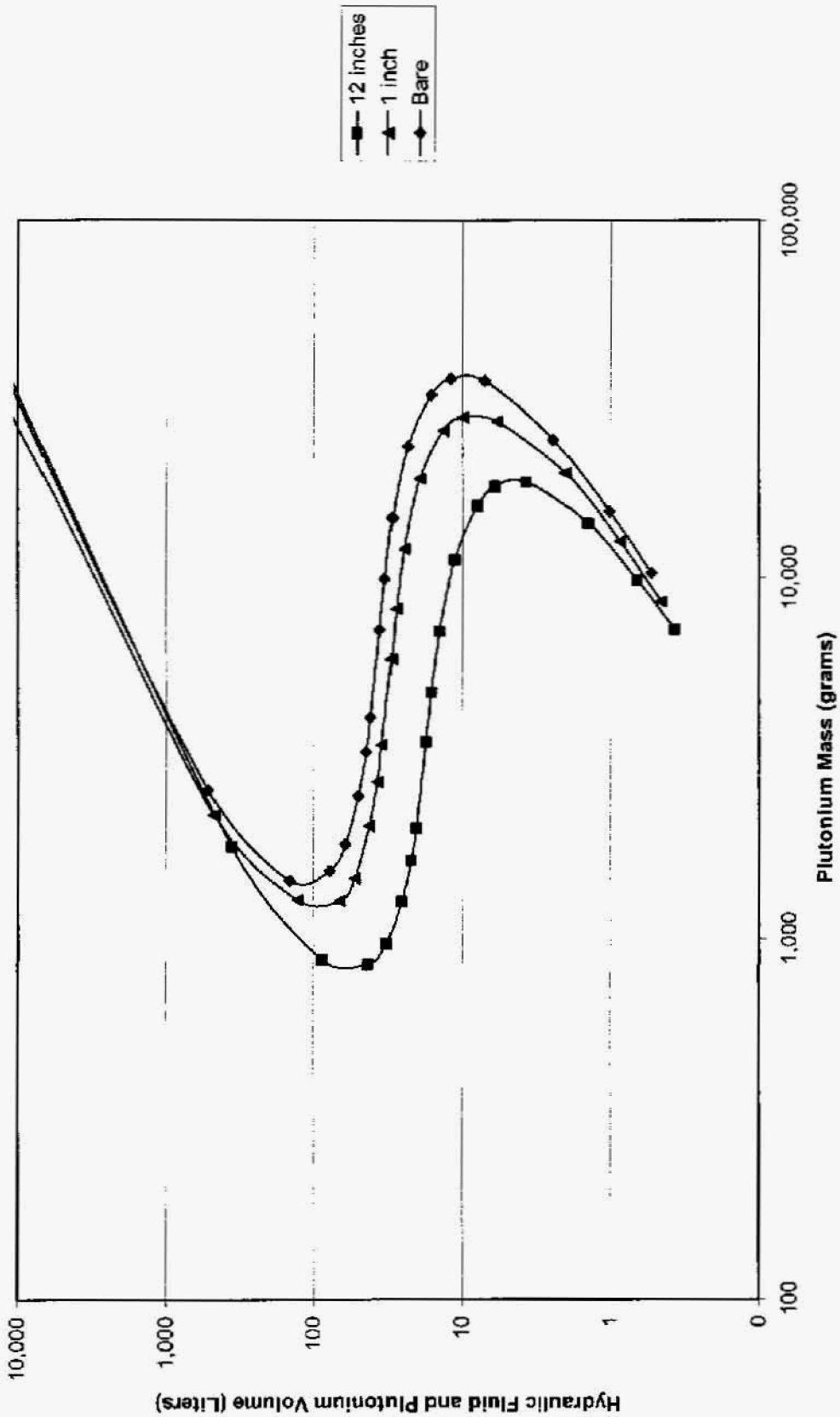

Figure 6-1. Critical Curves for Hydraulic Fluid

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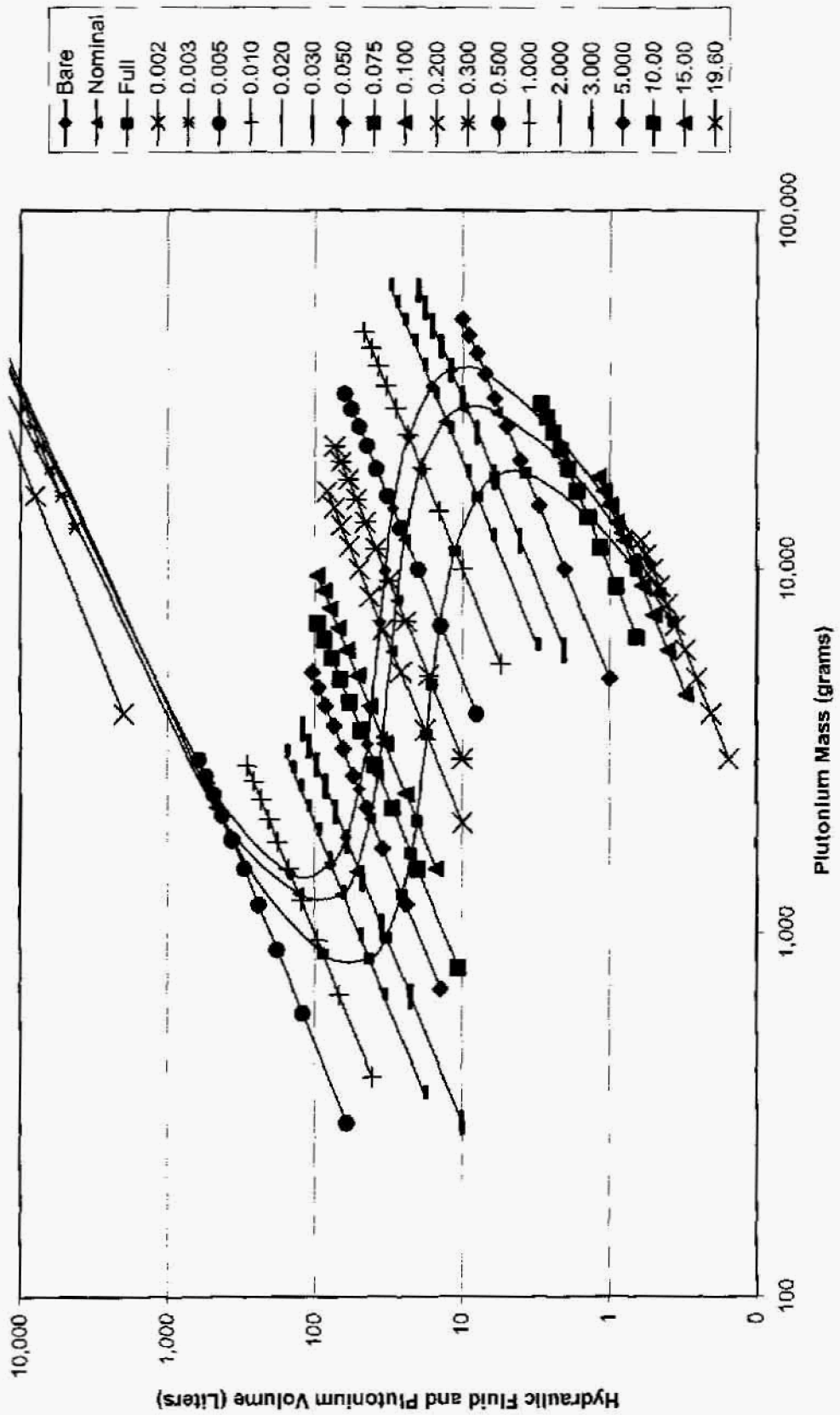

Figure 6-2. MCNP Complete Curves for Hydraulic Fluid

Table 6-1. Hydraulic Fluid Critical Curve Interpolated MCNP Calculated Results

Hydraulic Fluid Critical Curve Interpolated MCNP Calculated Results Minimum MCNP Calculated k_{eff} = 1.0 Masses with Voulumes are **bold**						
Pu density	Bare		1 Inch Reflection		12 Inches Reflection	
g/Liter	Volume (L)	Mass (g)	Volume (L)	Mass (g)	Volume (L)	Mass (g)
0.002	17,757,701.280	35,515,402.6	57,088,472.084	13,252,304.4	3,735,177.046	7,470,354.1
0.003	14,362.584	43,087.8	20,743.707	45,670.0	24,069.555	72,208.7
0.005	515.601	2,578.0	473.841	2,204.9	361.655	1,808.3
0.010	**145.065**	**1,450.6**	128.057	1,281.4	87.639	876.4
0.020	77.272	1,545.4	**66.341**	**1,272.8**	**42.529**	**850.6**
0.030	60.918	1,827.5	52.189	1,472.0	32.366	971.0
0.050	49.592	2,479.6	41.859	2,056.6	25.423	1,271.2
0.075	43.890	3,291.7	36.949	2,718.4	22.052	1,653.9
0.100	40.927	4,092.7	34.500	3,446.1	20.355	2,035.5
0.200	35.721	7,144.2	29.895	5,926.4	17.562	3,512.3
0.300	33.026	9,907.9	27.640	8,196.1	16.071	4,821.3
0.500	29.324	14,661.8	24.467	12,043.6	14.211	7,105.7
1.000	23.310	23,310.0	19.424	18,886.8	11.244	11,244.1
2.000	16.234	32,467.5	13.468	25,752.4	7.943	15,886.0
3.000	11.996	35,989.5	9.918	28,100.1	5.998	17,992.5
5.000	7.113	35,566.1	5.873	27,371.1	3.699	18,496.3
10.000	2.428	24,281.9	2.022	19,574.2	1.418	14,184.3
15.000	1.017	15,249.0	0.862	12,637.8	0.660	9,894.8
19.600	0.526	10,301.9	0.451	8,585.9	0.367	7,184.3

Geometry is conservatively analyzed as a sphere. Mass was interpolated for k_{eff} = 1.00 for the critical curves. Volume of the critical sphere is calculated from the mass (grams) divided by the concentration (g/cm^3) and converted to Liters.

Density, concentration, and chemistry are all unrestricted because fissile material form is unrestricted.

Neutron moderation is unrestricted. Moderation, within the allowed maximum total volume for each Plutonium concentration, is used in the analysis.

There are no neutron absorbers credited for criticality safety in this analysis. The plutonium is mixed with hydraulic fluid, the reflector is hydraulic fluid, outside the reflector is air and the end of the MCNP mathematical model. There were no neutron interaction items taken into account in the generation of these critical curves.

7.0 REFERENCES

Carter, R. D., G. R. Kiel, and G. R. Ridgeway, 1968, *Criticality Handbook*, ARH-600, Atlantic Hanford Company, Richland, Washington.

Crowe, R. D., and R. W. Szempruch, 1994, *Technical Basis for Characterization of Plutonium for PFP Safety Analyses*, WHC-SD-CP-TI-190, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

FH, 2006, *Criticality Safety Program*, HNF-7098, Rev. 14, Fluor Hanford, Inc., Richland, Washington.

FH, 2007, *PHMC Calculation Preparation and Issue (Including OCRWM)*, HNF-PRO-8259, Rev. 3, Fluor Hanford, Inc., Richland, Washington.

APPENDIX A – INDEPENDENT REVIEW COMMENTS AND CHECKLIST

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CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed - HNF-33756, Rev. 0

Title: Criticality Curves for Plutonium Hydraulic Fluid Mixtures

Author(s): W. D. Wittekind

Date: August 2007

Scope of Review: Review of the document excluding the spreadsheets and MCNP.

Yes	No*	NA		
[✓]	[ ]	[ ]		Referenced analyses appropriate.
[✓]	[ ]	[ ]		Problem completely defined and all potential configurations considered.
[ ]	[ ]	[✓]		Accident scenarios developed in a clear and logical manner.
[✓]	[ ]	[ ]		Necessary assumptions explicitly stated and supported.
[✓]	[ ]	[ ]		Computer codes and data files documented.
[✓]	[ ]	[ ]		Data used in calculations explicitly stated in document.
[✓]	[ ]	[ ]		Data checked for consistency with original source information as applicable.
[ ]	[ ]	[✓]		Mathematical derivations checked including dimensional consistency of results
[✓]	[ ]	[ ]		Models appropriate and used within range of validity, or use outside range of established validity justified.
[ ]	[ ]	[✓]		Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[ ]	[ ]	[✓]		Software input correct and consistent with document reviewed.
[ ]	[ ]	[✓]		Software output consistent with input and with results reported in document reviewed.
[ ]	[ ]	[✓]		Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[ ]	[ ]	[✓]		Safety margins consistent with good engineering practices.
[✓]	[ ]	[ ]		Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]		Results and conclusions address all points required in the problem statement.
[✓]	[ ]	[ ]		Format consistent with applicable guides or other standards.
[ ]	[ ]	[✓]	**	Review calculations, comments, and/or notes are attached.
[✓]	[ ]	[ ]		Document approved (for example, the reviewer affirms the technical accuracy of the document).

R. F. Richard R.F. Richard — 9/26/07
Technical Peer Reviewer (printed name and signature) — Date

* All "no" responses must be explained below or on an additional sheet.

** Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. The material should be labeled and recorded in such a manner as to be understandable to a technically qualified third party.

Criticality Curves for Plutonium Hydraulic Fluid Mixtures
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CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed - HNF-33756, Rev. 0

Title: Criticality Curves for Plutonium Hydraulic Fluid Mixtures

Author(s): W. D. Wittekind

Date: August 2007

Scope of Review: Review of Spreadsheets and MCNP Only

Yes	No*	NA		
[✓]	[ ]	[ ]		Referenced analyses appropriate.
[✓]	[ ]	[ ]		Problem completely defined and all potential configurations considered.
[ ]	[ ]	[✓]		Accident scenarios developed in a clear and logical manner.
[✓]	[ ]	[ ]		Necessary assumptions explicitly stated and supported.
[✓]	[ ]	[ ]		Computer codes and data files documented.
[✓]	[ ]	[ ]		Data used in calculations explicitly stated in document.
[✓]	[ ]	[ ]		Data checked for consistency with original source information as applicable.
[✓]	[ ]	[ ]		Mathematical derivations checked including dimensional consistency of results
[✓]	[ ]	[ ]		Models appropriate and used within range of validity, or use outside range of established validity justified.
[✓]	[ ]	[ ]		Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[✓]	[ ]	[ ]		Software input correct and consistent with document reviewed.
[✓]	[ ]	[ ]		Software output consistent with input and with results reported in document reviewed.
[ ]	[ ]	[✓]		Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[ ]	[ ]	[✓]		Safety margins consistent with good engineering practices.
[✓]	[ ]	[ ]		Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]		Results and conclusions address all points required in the problem statement.
[✓]	[ ]	[ ]		Format consistent with applicable guides or other standards.
[ ]	[ ]	[✓]	**	Review calculations, comments, and/or notes are attached.
[✓]	[ ]	[ ]		Document approved (for example, the reviewer affirms the technical accuracy of the document).

S. F. Kessler S. F. Kessler 9/17/07
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** Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. The material should be labeled and recorded in such a manner as to be understandable to a technically qualified third party.

APPENDIX B – MCNP COMPUTER CODE VALIDATION

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MCNP4C COMPUTER CODE VALIDATION

B.1 VALIDATION PROCEDURE

Validation of the MCNP4C computer code methods consisted of testing the code and its neutron cross section libraries against experiments of known critical configuration. These benchmark experiments have fissile isotopes in systems similar to those evaluated in this CSER. The computed and measured k_{eff} values for the benchmark configurations were compared to establish a bias that includes the uncertainty in the calculational methods. A bias-adjusted k_{eff} for the benchmark systems was defined to include both the deviations of the calculated from the measured k_{eff} values, and experimental and calculation uncertainties along with a conservative allowance (a safety margin) for differences between the analyzed benchmarks and systems analyzed for this CSER. In addition, criticality safety criteria require that the bias-adjusted k_{eff} for CSER analysis calculations not exceed the established k_{eff} safety limit at the 95% confidence level.

This method is illustrated in Figure B-1. Critical is defined as a k_{eff} of unity, adjusted by the bias established from the comparison of calculations with benchmarks. The bias is combined with the safety margin of 0.05 (a safety limit that k_{eff} must be less than or equal to 0.95) to compare with the calculated value and statistical uncertainty of the computer calculated k_{eff} values in this CSER analysis. The calculated target k_{eff} is established by adding the bias, 0.05, and 1.645 times the one-sigma uncertainty of the calculated k_{eff} for the particular CSER analysis and subtracting that value from 1.0. For the analyses in this CSER, all of the computer statistical uncertainties were less than ± 0.002, so this value was used to set the k_{eff} limits, as described in Section B.2.

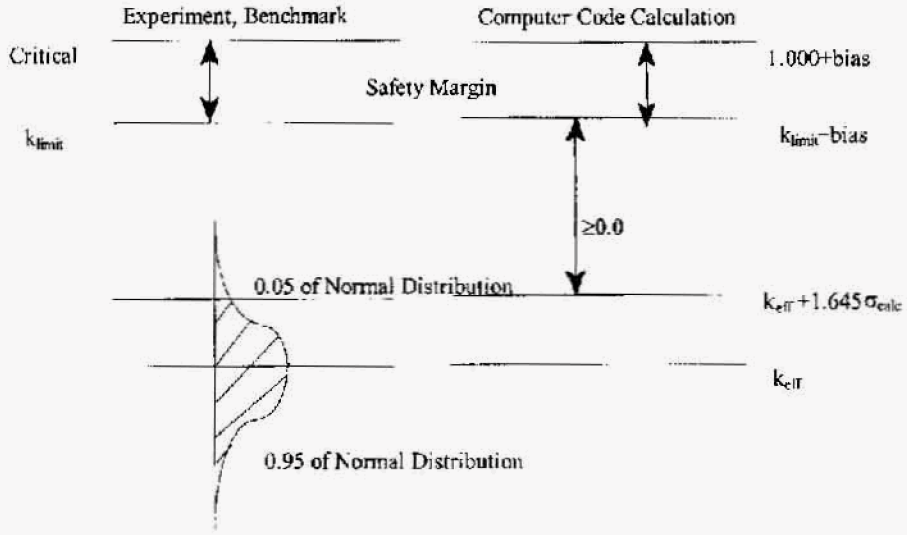

Figure B-1. Logic of Validation Procedure

B.2 GENERIC VALIDATION FOR PLUTONIUM SYSTEMS

A report, *Engineering Computer Program Approval for Use*, 620.290.MCNP4C, Rev. 1 (Lan 2003), presents the results of calculations to determine a generic bias for plutonium configurations, as encountered in the Plutonium Finishing Plant. One hundred and forty three benchmark experiments were calculated. There were different material types that were considered in the plutonium validation calculations:

- Plutonium metal,
- Plutonium oxide,
- Plutonium solutions,
- Plutonium solutions with cadmium (a neutron poison),
- Water and polystyrene moderators, and
- Water, Plexiglas, paraffin, polyethylene, and steel and concrete reflectors

The lower tolerance limit b_L was calculated for the benchmark experiments such that there is 95% confidence that 95% of the benchmark calculated k_{eff}'s is above that limit. This is expressed by the following formula:

$$b_L = k_{avg} - K_b * \sigma_{avg}$$

where: b_L = lower tolerance limit for 95% confidence that 95% of the benchmark calculated k_{eff}'s is above this limit,
k_{avg} = the average of the k_{eff}'s calculated by MCNP4C,
K_b = a multiplier found from statistical tables for non-central t-distribution, and depends on number of degrees of freedom, and
σ_{avg} = standard deviation of the MCNP k_{eff}'s.

Bias is calculated by the following formula:

$$bias = b_L - k_{crit}$$

where:

k_{crit} = the average of the k_{eff}'s for the critical experiments; for the plutonium experiments $k_{eff} = 1.000$.

The bias for the plutonium metal group was significantly different than for all other groups. For this reason, it was concluded that separate bias values for metal and non-metal groupings would be appropriate. The lower tolerance limit for the metal group (17 benchmark critical experiments) calculated to be 0.9884. The lower tolerance limit for the non-metal group (126 benchmark critical experiments) calculated to be 0.9991. These lower tolerance limits yielded the bias appropriate for each material category:

- Plutonium metal bias is -0.0116,
- Plutonium non-metal bias is -0.0009.

For conservatism, these calculated biases were recommended to be increased to:

- Plutonium metal recommended bias is -0.0150,
- Plutonium non-metal recommended bias is -0.0050.

The safety criteria for future calculations on undetermined systems require that the bias adjusted k_{eff} does not exceed 0.95 at the 95% confidence level. This is expressed by the following formula:

$$k_{eff}^{*} = k_{eff} - \text{bias} + 1.645 * \sigma_{calc} \leq k_{limit}$$

where: k_{eff} = k value given by MCNP4C calculation for system in question,
bias = -0.015 for Pu metal, and -0.005 for Pu non-metal systems,
1.645 = a constant number of standard deviations for 0.95 of the distribution for a one-sided standard normal distribution
σ_{calc} = standard deviation given by MCNP4C calculation for system in question, and
k_{limit} = 0.95 for plutonium systems, generally.

k_{limit} is generally taken to be 0.95 for plutonium systems.

For a standard deviation (σ_{calc}) of 0.001 or less, the k_{eff} value for plutonium metal systems is:

$$k_{eff} - (-0.015) + 1.645 * 0.001 \leq 0.95, \text{ or}$$

$$k_{eff} \leq 0.95 + (-0.015) - 1.645 * 0.001 = 0.933.$$

On this basis, it is determined that the true k_{eff} of an analyzed configuration with plutonium will not exceed 0.95 with a 95% confidence level for plutonium metal systems if the calculated value (k_{eff}, and $\sigma \leq 0.001$) is limited to a maximum value of **0.933**, as illustrated in Figure B-2.

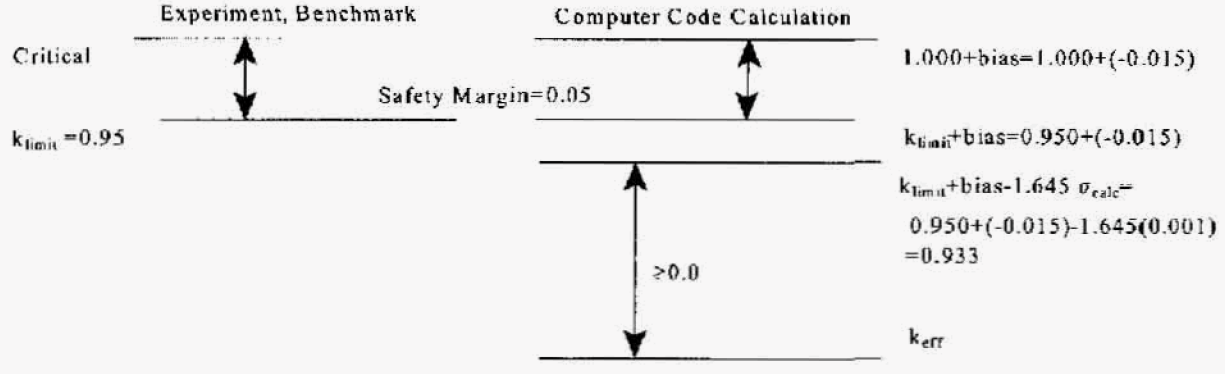

Figure B-2. Implementation of Validation Procedure for Plutonium Metal Systems

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For a standard deviation (σ_{calc}) of 0.001 or less, the k_{eff} value for non-metal systems is:

$$k_{eff} - (-0.005) + 1.645 * 0.001 \leq 0.95, \text{ or}$$
$$k_{eff} \leq 0.95 + (-0.005) - 1.645 * 0.001 = 0.943.$$

On this basis, it is determined that the true k_{eff} of an analyzed configuration with plutonium will not exceed 0.95 with a 95% confidence level for plutonium non-metal systems if the calculated value (k_{eff}, and $\sigma \leq 0.001$) is limited to a maximum value of **0.943**, as illustrated in Figure B-3.

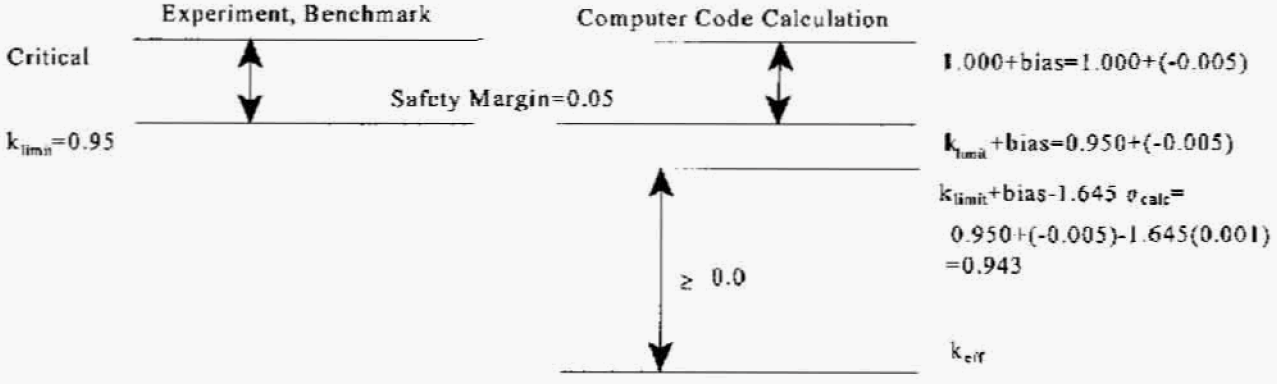

Figure B-3. Implementation of Validation Procedure for Moderated or Oxidized Plutonium Systems

B.3 VALIDATION OF MCNP4C

The validation of the MCNP4C code (Briesmeister 2001) on personal computers connected to the Fluor Local Area Network (FLAN) was documented in Lan 2003. These computers Dell® Precision® 360 workstations operating under Microsoft® WindowsXP® Professional Version 5.1.2600

The essence of the validation was cross correlation of calculation results obtained with this code version and results of critical experiments.

B.4 REFERENCES

Briesmeister, J. F., Editor, 2001, *Monte Carlo N-Particle Transport Code System*, CCC-701, Transport Methods Group, Los Alamos National Lab., June, 2001, Los Alamos, New Mexico.

Lan, J. S., 2003, *Engineering Computer Program Approval for Use*, 620.290.MCNP4C, Rev. 1, Fluor Federal Services, Inc., Richland, Washington.

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APPENDIX C – HYDRAULIC FLUID COMPOSITION

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Wittekind, Warren D

From: Larkin, Keith A
Sent: Monday, May 14, 2007 1:34 PM
To: Wittekind, Warren D; Mcclellan, James A
Subject: HA-23S Hydraulic Fluid

Finally found where they drained the resevoir and replaced the fluid. It was performed per package 2Z-95-00088. The hydraulic fluid was replaced with Fyrquel 220. Chemical Name is: Butylated Triphenyl phosphate Mixtures.
Keith

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APPENDIX D – MCNP COMPUTER MODELING

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D.0 Summary

First, EXCEL[EXCEL®] spreadsheet for plutonium-hydraulic fluid composition calculations was performed. Then this data was entered into MCNP input programs, and then data from MCNP output was interpolated to yield critical curves for three spherical geometries:

- Bare,
- 1 inch hydraulic fluid reflection, and
- 12 inches hydraulic fluid reflection.

D.1 FYRQUEL® 220 Composition

The composition of Fyrquel® 220 is not exact, but is known fairly well. Representative MSDSs were consulted for the best available composition, as shown in Table D-1, *FYRQUEL® 220 Best Available Composition.*

Table D-1. FYRQUEL® 220 Best Available Composition

FYRQUEL® 220 Best Available Composition		
CAS #	Description	Composition
MSDS# 014029 revision 3 (dated04/24/2007) Given Composition For FYRQUEL® 220		
65632-41-7	Bis(t-butylphenyl) phenyl phosphate	30-35%
56803-37-3	t-Butylphenyl diphenyl phosphate	30-35%
115-86-6	Triphenyl phosphate	15-25%
78-33-1	Tri(t-butylphenyl) phosphate	10-15%
	Specific gravity = 1.13 1.17 g/cm^3 at 20 °C (68 °F)	
MSDS# 16-084447 (dated 10/29/1997) Given Composition For FYRQUEL® 220		
115-86-6	Triphenyl phosphate	15-25%
Mixture	Butylated triphenyl phosphate mixture	75-85%
	Specific gravity not determined	
MSDS# CGLTW (dated 12/08/1999) Given Composition For FYRQUEL® 220		
115-86-6	Triphenyl phosphate	15-25%
Mixture	Butylated triphenyl phosphate mixture	75-85%
	Specific gravity not determined	
MSDS# 184048 (dated 10/09/1998) Given Composition For FYRQUEL® 220		
115-86-6	Triphenyl phosphate	15-25%
56803373	Phosphoric Acid, (1,1-Dimethylethyl)phenyl diphenyl ester	75-85%
	Specific gravity = 1 g/cm^3	

MSDS # 014029 had enough information that an average FRYQUEL® 220 composition could be calculated. This was performed as shown in Table D-2, *Spreadsheet Calculation for Effective FYRQUEL® 220 Composition*. Density of 1.17 g/cm^3 was used in these EXCEL + MCNP calculations.

EXCEL® is a registered trademark of Microsoft Corporation.

Table D-2. Spreadsheet Calculation for Effective FYRQUEL® 220 Composition

Spreadsheet Calculation for Effective FYRQUEL® 220 Composition							
	CAS # =	65652-41-7	56803-37-3	115-86-6	78-33-1		
Carbon	C	16	22	18	30		
Hydrogen	H	18	23	15	39		
Oxygen	O	4	4	4	4		
Phosphorus	P	1	1	1	1		
	Minimum	30	30	15	10	85	Minimum
	Maximum	35	35	25	15	110	Maximum
	Spread	5	5	10	5	25	Spread
	0.6	33	33	21	13	100	Normalized
	C	5.28	7.26	3.78	3.9	**20.22**	
	H	5.94	7.59	3.15	5.07	**21.75**	
	O	1.32	1.32	0.84	0.52	**4**	
	P	0.33	0.33	0.21	0.13	1	

D.2 Introduction

The goal was to produce a critical curve for plutonium (0 wt% ^{240}Pu) for spheres that had:

- No reflection (Bare),
- 1 inch hydraulic fluid reflection (nominal reflection), and
- 12 inches hydraulic fluid reflection (full reflection).

The hydraulic was identified as Fyrquel® 220. The MSDS selected gave $C_{20.22}H_{21.75}O_4P$ as the effective molecular formula.

D.3 EXCEL Spreadsheets for Plutonium and Hydraulic Fluid Composition

EXCEL spreadsheets reproduced as Table D-3, *MCNP Composition and Dimensions for Pu-Hydraulic Fluid 0.003 g/cm^3*, Table D-4, *MCNP Composition and Dimensions for Pu-Hydraulic Fluid 0.075 g/cm^3*, and Table D-5, *MCNP Composition and Dimensions for Pu-Hydraulic Fluid 3.000 g/cm^3*.

The EXCEL spreadsheets calculated the Pu-hydraulic fluid mixture composition for plutonium densities from 19,600 grams per Liter down to 2 grams per Liter to cover the entire range of plutonium fluid mixtures. This was intended to produce a curve similar to Figure III.A.9(100)-4, *Critical Sphere Volume vs. Critical Sphere Mass Plutonium-H_2O – 0 wt% ^{240}Pu*, from the ARH-600 criticality handbook

Ten MCNP cases were executed for each Pu density in the (1) Bare, (2) 1" fluid, and (3) 12" fluid reflection configurations. Then interpolation was performed to locate $k_{eff} = 1.000$ from the data. This gave a spherical mass, and because the Pu density was fixed, the plutonium volume for that Pu density. A "Bare" critical curve was produced by connecting all the Pu densities for the bare critical spherical configuration.

D.4 MCNP Input Files

There are three MCNP input files listed in this appendix at different plutonium concentrations.

D.5 Lagrangian Interpolation for Critical Points

The calculated values of k_{eff} from the MCNP calculations were used as base points for Lagrangian polynomial interpolation. Each plutonium concentration was MCNP computed for ten different masses. Then MCNP calculated the k_{eff} for each mass at this specific plutonium concentration. It is desired to know the mass where $k_{eff} = 1.000$. The k_{eff} is the independent variable, x_i, while the mass is dependent variable, $F(x_i)$. The 3-point Lagrangian polynomial was then used to determine $k_{eff} = 1.000$. There is some curvature in the mass versus k_{eff} curve, so quadratic interpolation was used instead of linear (two point) interpolation. These calculations were performed in EXCEL using the MCNP4C k_{eff} values to high precision.

Given the Lagrangian interpolation polynomial (F(x) ≈mass, and x ≈k_{eff}) and x = 1.000:

$$F(x) = \sum_{i=1}^{3} \prod_{\substack{j=1 \\ j \neq i}}^{3} \frac{(x - x_j)}{(x_i - x_j)} F(x_i) \tag{1}$$

Or, in explicit form, where x=1 has been substituted, this interpolation would appear as in (2).

$$F(x) = \frac{(1 - x_{i-1})(1 - x_{i-2})}{(x_i - x_{i+1})(x_i - x_{i+2})} F(x_i) + \frac{(1 - x_i)(1 - x_{i+2})}{(x_{i+1} - x_i)(x_{i+1} - x_{i+2})} F(x_{i+1}) + \frac{(1 - x_i)(1 - x_{i+1})}{(x_{i+2} - x_i)(x_{i+2} - x_{i+1})} F(x_{i+2}) \tag{2}$$

The most appropriate interpolation is where at least one point is on each side of the $k_{eff} = 1$ desired value. Finally, after the interpolated mass at $k_{eff} = 1$ has been determined, then the plutonium concentration is divided into the mass to determine the volume of this critical configuration.

The critical masses along with the critical volumes are then plotted as points on a critical curve of mass versus volume for each of the three geometries.

Table D-3. MCNP Composition and Dimensions for Pu-Hydraulic Fluid 0.003 g/cm^3

Input is Pu (g/L), Pu Mass (g) (10 evenly spaced), Output is MCNP composition, sphere dimensions

MCNP Composition and Dimensions for Plutonium-Hydraulic Fluid 0.003 g/cm^3												
239.0522	Pu - C20.22H21.75O4P											
240.0540	^{240}Pu/Pu wt%	0	0	0	0	0	0	0	0	0	0	INPUT
H	Mass Pu	13,000	16,000	19,000	22,000	25,000	28,000	31,000	34,000	37,000	40,000	INPUT
1.00797	Pu(g/cm^3)	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	INPUT
C	Pu (grams/L)	3	3	3	3	3	3	3	3	3	3	
12.0111												
O	Vol Pu (cm^3)	663.26531	816.32653	969.38776	1122.449	1275.5102	1428.5714	1581.6327	1734.6939	1887.7551	2040.8163	
15.9994	Vol Hyd. Oil	4332670.1	5332517	6332363.9	7332210.9	8332057.8	9331904.8	10331752	11331599	12331446	13331293	
P	Vol. Total	4333333.3	5333333.3	6333333.3	7333333.3	8333333.3	9333333.3	10333333	11333333	12333333	13333333	
30.97376												
	Mass Pu	13000	16000	19000	22000	25000	28000	31000	34000	37000	40000	
21.75	Mass Hyd. Oil	5069224	6239045	7408866	8578687	9748508	10918329	12088149	13257970	14427791	15597612	
20.22	Mass Total	5082224	6255045	7427866	8600687	9773508	10946329	12119149	13291970	14464791	15637612	
4												
1	H/Pu	5635.58	5635.58	5635.58	5635.58	5635.58	5635.58	5635.58	5635.58	5635.58	5635.58	OUTPUT
19.6	Density	1.172821	1.172821	1.172821	1.172821	1.172821	1.172821	1.172821	1.172821	1.172821	1.172821	OUTPUT
1.17	Density Pu	0.003000	0.003000	0.003000	0.003000	0.003000	0.003000	0.003000	0.003000	0.003000	0.003000	
wt% H	1001.50c	-0.060783	-0.060783	-0.060783	-0.060783	-0.060783	-0.060783	-0.060783	-0.060783	-0.060783	-0.060783	OUTPUT
wt% C	6000.50c	-0.673348	-0.673348	-0.673348	-0.673348	-0.673348	-0.673348	-0.673348	-0.673348	-0.673348	-0.673348	OUTPUT
wt% O	8016.50c	-0.177435	-0.177435	-0.177435	-0.177435	-0.177435	-0.177435	-0.177435	-0.177435	-0.177435	-0.177435	OUTPUT
wt% P	15031.50c	-0.085876	-0.085876	-0.085876	-0.085876	-0.085876	-0.085876	-0.085876	-0.085876	-0.085876	-0.085876	OUTPUT
wt% ^{239}Pu	94239.55c	-0.002558	-0.002558	-0.002558	-0.002558	-0.002558	-0.002558	-0.002558	-0.002558	-0.002558	-0.002558	OUTPUT
wt% ^{240}Pu	94240.50c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	OUTPUT
	Sum	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
	Sphere (cm)	101.137255	108.385214	114.775161	120.523279	125.769900	130.611893	135.119266	139.344453	143.327861	147.101367	OUTPUT
	Sph. 1" Ref cm	103.677255	110.925214	117.315161	123.063279	128.309900	133.151893	137.659266	141.884453	145.867861	149.641367	OUTPUT
	Sph. 12" Ref cm	131.617255	138.865214	145.255161	151.003279	156.249900	161.091893	165.599266	169.824453	173.807861	177.581367	OUTPUT
wt% H	1001.50c	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	OUTPUT
wt% C	6000.50c	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	OUTPUT
wt% O	8016.50c	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	OUTPUT
wt% P	15031.50c	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	OUTPUT
	Sum	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	

Table D-4. MCNP Composition and Dimensions for Pu-Hydraulic Fluid 0.075 g/cm^3

Input is Pu (g/L), Pu Mass (g) (10 evenly spaced), Output is MCNP composition, sphere dimensions

MCNP Composition and Dimensions for Plutonium-Hydraulic Fluid 0.075 g/cm^3												
239.0522	Pu - C20.22H21.75O4P											
240.0540	^{240}Pu/Pu wt%	0	0	0	0	0	0	0	0	0	0	INPUT
H	Mass Pu	800	1,500	2,200	2,900	3,600	4,300	5,000	5,700	6,400	7,100	INPUT
1.00797	Pu(g Pu/cm^3)	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	INPUT
C	Pu (grams/L)	75	75	75	75	75	75	75	75	75	75	
12.0111												
O	Vol Pu (cm^3)	40.81633	76.53061	112.2449	147.9592	183.6735	219.3878	255.102	290.8163	326.5306	362.2449	
15.9994	Vol Hyd. Oil	10625.85	19923.47	29221.09	38518.71	47816.33	57113.95	66411.56	75709.18	85006.8	94304.42	
P	Vol. Total	10666.67	20000	29333.33	38666.67	48000	57333.33	66666.67	76000	85333.33	94666.67	
30.97376												
	Mass Pu	800	1500	2200	2900	3600	4300	5000	5700	6400	7100	
21.75	Mass Hyd. Oil	12432	23310	34189	45067	55945	66823	77702	88580	99458	110336	
20.22	Mass Total	13232	24810	36389	47967	59545	71123	82702	94280	105858	117436	
4												
1	H/Pu	224.59	224.59	224.59	224.59	224.59	224.59	224.59	224.59	224.59	224.59	OUTPUT
19.6	Density	1.240523	1.240523	1.240523	1.240523	1.240523	1.240523	1.240523	1.240523	1.240523	1.240523	OUTPUT
1.17	Density Pu	0.075000	0.075000	0.075000	0.075000	0.075000	0.075000	0.075000	0.075000	0.075000	0.075000	
wt% H	1001.50c	-0.057255	-0.057255	-0.057255	-0.057255	-0.057255	-0.057255	-0.057255	-0.057255	-0.057255	-0.057255	OUTPUT
wt% C	6000.50c	-0.634261	-0.634261	-0.634261	-0.634261	-0.634261	-0.634261	-0.634261	-0.634261	-0.634261	-0.634261	OUTPUT
wt% O	8016.50c	-0.167135	-0.167135	-0.167135	-0.167135	-0.167135	-0.167135	-0.167135	-0.167135	-0.167135	-0.167135	OUTPUT
wt% P	15031.50c	-0.080891	-0.080891	-0.080891	-0.080891	-0.080891	-0.080891	-0.080891	-0.080891	-0.080891	-0.080891	OUTPUT
wt% ^{239}Pu	94239.55c	-0.060458	-0.060458	-0.060458	-0.060458	-0.060458	-0.060458	-0.060458	-0.060458	-0.060458	-0.060458	OUTPUT
wt% ^{240}Pu	94240.50c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	OUTPUT
	Sum	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
	Sphere (cm)	13.655681	16.838903	19.131878	20.977290	22.545033	23.920844	25.153980	26.276952	27.311363	28.272844	OUTPUT
	Sph. 1" Ref cm	16.195681	19.378903	21.671878	23.517290	25.085033	26.460644	27.693980	28.816952	29.851363	30.812844	OUTPUT
	Sph. 12" Ref cm	44.135681	47.318903	49.611878	51.457290	53.025033	54.400644	55.633980	56.756952	57.791363	58.752844	OUTPUT
wt% H	1001.50c	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	OUTPUT
wt% C	6000.50c	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	OUTPUT
wt% O	8016.50c	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	OUTPUT
wt% P	15031.50c	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	OUTPUT
	Sum	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	

Table D-5. MCNP Composition and Dimensions for Pu-Hydraulic Fluid 3.000 g/cm^3

Input is Pu (g/L), Pu Mass (g) (10 evenly spaced), Output is MCNP composition, sphere dimensions

MCNP Composition and Dimensions for Pu-Hydraulic Fluid 3.000 g/cm^3												
239.0522	Pu - C20.22H21.75O4P											
240.0540	^{240}Pu/Pu wt%	0	0	0	0	0	0	0	0	0	0	INPUT
H	Mass Pu	6000	12000	18000	24000	30000	36000	42000	48000	54000	60000	INPUT
1.00797	Pu(g Pu/cm^3)	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	INPUT
C	Pu (grams/L)	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	
12.0111												
O	Vol Pu (cm^3)	306.1224	612.2449	918.3673	1224.49	1530.612	1836.735	2142.857	2448.98	2755.102	3061.224	
15.9994	Vol Hyd. Oil	1693.878	3387.755	5081.633	6775.51	8469.388	10163.27	11857.14	13551.02	15244.9	16938.78	
P	Vol. Total	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000	
30.97376												
	Mass Pu	6000	12000	18000	24000	30000	36000	42000	48000	54000	60000	
21.75	Mass Hyd. Oil	1982	3964	5946	7927	9909	11891	13873	15855	17837	19818	
20.22	Mass Total	7982	15964	23946	31927	39909	47891	55873	63855	71837	79818	
4												
1	H/Pu	4.77	4.77	4.77	4.77	4.77	4.77	4.77	4.77	4.77	4.77	OUTPUT
19.6	Density	3.990918	3.990918	3.990918	3.990918	3.990918	3.990918	3.990918	3.990918	3.990918	3.990918	OUTPUT
1.17	Density Pu	3.000000	3.000000	3.000000	3.000000	3.000000	3.000000	3.000000	3.000000	3.000000	3.000000	
wt% H	1001.50c	-0.015131	-0.015131	-0.015131	-0.015131	-0.015131	-0.015131	-0.015131	-0.015131	-0.015131	-0.015131	OUTPUT
wt% C	6000.50c	-0.167617	-0.167617	-0.167617	-0.167617	-0.167617	-0.167617	-0.167617	-0.167617	-0.167617	-0.167617	OUTPUT
wt% O	8016.50c	-0.044169	-0.044169	-0.044169	-0.044169	-0.044169	-0.044169	-0.044169	-0.044169	-0.044169	-0.044169	OUTPUT
wt% P	15031.50c	-0.021377	-0.021377	-0.021377	-0.021377	-0.021377	-0.021377	-0.021377	-0.021377	-0.021377	-0.021377	OUTPUT
wt% ^{239}Pu	94239.55c	-0.751707	-0.751707	-0.751707	-0.751707	-0.751707	-0.751707	-0.751707	-0.751707	-0.751707	-0.751707	OUTPUT
wt% ^{240}Pu	94240.50c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	OUTPUT
	Sum	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
	Sphere (cm)	7.815926	9.847450	11.272517	12.407010	13.365046	14.202481	14.951329	15.631853	16.257782	16.838903	OUTPUT
	Sph. 1" Ref cm	10.355926	12.387450	13.812517	14.947010	15.905046	16.742481	17.491329	18.171853	18.797782	19.378903	OUTPUT
	Sph. 12" Ref cm	38.295926	40.327450	41.752517	42.887010	43.845046	44.682481	45.431329	46.111853	46.737782	47.318903	OUTPUT
wt% H	1001.50c	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	-0.060939	OUTPUT
wt% C	6000.50c	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	-0.675075	OUTPUT
wt% O	8016.50c	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	-0.177890	OUTPUT
wt% P	15031.50c	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	-0.086096	OUTPUT
	Sum	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	

Criticality Curves for Plutonium Hydraulic Fluid Mixtures
HNF-33756, Rev. 0

Representative MCNP input files are included.

Hyoil00RN00003m19000.inp (Spherical Pu-hydraulic fluid 3 g/L, 19,000 g Pu)
Hyoil00RF00075m02900.inp (Spherical Pu-hydraulic fluid 75 g/L, 2,900 g Pu)
Hyoil00RB03000m18000.inp (Spherical Pu-hydraulic fluid 3,000 g/L, 18,000 g Pu)

Hyoil00RN00003m19000.inp

```
message:

Pu  0.003 g/cm3 19000 grams
 1   1   -1.172821    -1          imp:n=1 $ hydraulic fluid+Pu sphere
 2   3   -1.17        -2     1    imp:n=1 $ hydraulic fluid
 3   3   -1.29E-3     -3     2    imp:n=1 $ Air Space
 4   0                       3    imp:n=0 $ outside world

c  1  so   101.137255                    $ 13000 gram Pu sphere
c  2  so   103.677255                    $  1 inch   hydraulic fluid
c  2  so   131.617255                    $ 12 inches hydraulic fluid
c  1  so   108.385214                    $ 16000 gram Pu sphere
c  2  so   110.925214                    $  1 inch   hydraulic fluid
c  2  so   138.865214                    $ 12 inches hydraulic fluid
   1  so   114.775161                    $ 19000 gram Pu sphere
   2  so   117.315161                    $  1 inch   hydraulic fluid
c  2  so   145.255161                    $ 12 inches hydraulic fluid
c  1  so   120.523279                    $ 22000 gram Pu sphere
c  2  so   123.063279                    $  1 inch   hydraulic fluid
c  2  so   151.003279                    $ 12 inches hydraulic fluid
c  1  so   125.769900                    $ 25000 gram Pu sphere
c  2  so   128.309900                    $  1 inch   hydraulic fluid
c  2  so   156.249900                    $ 12 inches hydraulic fluid
c  1  so   130.611893                    $ 28000 gram Pu sphere
c  2  so   133.151893                    $  1 inch   hydraulic fluid
c  2  so   161.091893                    $ 12 inches hydraulic fluid
c  1  so   135.119266                    $ 31000 gram Pu sphere
c  2  so   137.659266                    $  1 inch   hydraulic fluid
c  2  so   165.599266                    $ 12 inches hydraulic fluid
c  1  so   139.344453                    $ 34000 gram Pu sphere
c  2  so   141.884453                    $  1 inch   hydraulic fluid
c  2  so   169.824453                    $ 12 inches hydraulic fluid
c  1  so   143.327861                    $ 37000 gram Pu sphere
c  2  so   145.867861                    $  1 inch   hydraulic fluid
c  2  so   173.807861                    $ 12 inches hydraulic fluid
c  1  so   147.101367                    $ 40000 gram Pu sphere
c  2  so   149.641367                    $  1 inch   hydraulic fluid
c  2  so   177.581367                    $ 12 inches hydraulic fluid
   3  so   199.000000                    $ outside world

mode n
tmp      2.585e-6     2r                $ 001 - 003    300K everywhere
         1j                             $ outside world
kcode  24000   1.0   50  550
ksrc     0.00    0.00    0.00
m1     1001.50c   -0.060783             $ Plutonium hydraulic fluid sphere
       6000.50c   -0.673348
       8016.50c   -0.177435
      15031.50c   -0.085876
      94239.55c   -0.002558
mt1   lwtr.01t                          $ 300 K = 27 C = 80.6 F
m2     1001.50c   -0.060939             $ hydraulic fluid
       6000.50c   -0.675075
       8016.50c   -0.177890
      15031.50c   -0.086096
mt2   lwtr.01t                          $ 300 K = 27 C = 80.6 F
m3     8016.50c    0.20                 $ Air
       7014.50c    0.80
totnu
ctme   14480.
print    30 40 60 110 126 140 170
```

Hyoil00RF00075m02900.inp

```
message:

Pu  0.075 g/cm3  2900 grams
 1   1   -1.240523    -1          imp:n=1 $ hydraulic fluid+Pu sphere
 2   3   -1.17        -2    1     imp:n=1 $ hydraulic fluid
 3   3   -1.29E-3     -3    2     imp:n=1 $ Air Space
 4   0                       3     imp:n=0 $ outside world

c  1  so  13.655681                    $   800 gram Pu sphere
c  2  so  16.195681                    $  1 inch   hydraulic fluid
c  2  so  44.135681                    $ 12 inches hydraulic fluid
c  1  so  16.838903                    $  1500 gram Pu sphere
c  2  so  19.378903                    $  1 inch   hydraulic fluid
c  2  so  47.318903                    $ 12 inches hydraulic fluid
c  1  so  19.131878                    $  2200 gram Pu sphere
c  2  so  21.671878                    $  1 inch   hydraulic fluid
c  2  so  49.611878                    $ 12 inches hydraulic fluid
   1  so  20.977290                    $  2900 gram Pu sphere
c  2  so  23.517290                    $  1 inch   hydraulic fluid
   2  so  51.457290                    $ 12 inches hydraulic fluid
c  1  so  22.545033                    $  3600 gram Pu sphere
c  2  so  25.085033                    $  1 inch   hydraulic fluid
c  2  so  53.025033                    $ 12 inches hydraulic fluid
c  1  so  23.920644                    $  4300 gram Pu sphere
c  2  so  26.460644                    $  1 inch   hydraulic fluid
c  2  so  54.400644                    $ 12 inches hydraulic fluid
c  1  so  25.153980                    $  5000 gram Pu sphere
c  2  so  27.693980                    $  1 inch   hydraulic fluid
c  2  so  55.633980                    $ 12 inches hydraulic fluid
c  1  so  26.276952                    $  5700 gram Pu sphere
c  2  so  28.816952                    $  1 inch   hydraulic fluid
c  2  so  56.756952                    $ 12 inches hydraulic fluid
c  1  so  27.311363                    $  6400 gram Pu sphere
c  2  so  29.851363                    $  1 inch   hydraulic fluid
c  2  so  57.791363                    $ 12 inches hydraulic fluid
c  1  so  28.272844                    $  7100 gram Pu sphere
c  2  so  30.812844                    $  1 inch   hydraulic fluid
c  2  so  58.752844                    $ 12 inches hydraulic fluid
   3  so  99.000000                    $ outside world

mode n
tmp      2.585e-6      2r             $ 001 - 003    300K everywhere
         1j                           $ outside world
kcode  24000   1.0   50  550
ksrc    0.00    0.00    0.00
m1    1001.50c   -0.057255            $ Plutonium hydraulic fluid sphere
      6000.50c   -0.634261
      8016.50c   -0.167135
     15031.50c   -0.080891
     94239.55c   -0.060458
mt1  lwtr.01t                        $ 300 K = 27 C = 80.6 F
m2    1001.50c   -0.060939            $ hydraulic fluid
      6000.50c   -0.675075
      8016.50c   -0.177890
     15031.50c   -0.086096
mt2  lwtr.01t                        $ 300 K = 27 C = 80.6 F
m3    8016.50c    0.20               $ Air
      7014.50c    0.80
totnu
ctme  14480.
print   30 40 60 110 126 140 170
```

Hyoil00RB03000m18000.inp

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message:

Pu  3.000 g/cm3 18000 grams
 1   1   -3.990918     -1          imp:n=1 $ hydraulic fluid+Pu sphere
 2   3   -1.29E-3      -2     1    imp:n=1 $ hydraulic fluid
 3   3   -1.29E-3      -3     2    imp:n=1 $ Air Space
 4   0                        3    imp:n=0 $ outside world

c  1  so   7.815926                    $  6000 gram Pu sphere
c  2  so  10.355926                    $  1 inch   hydraulic fluid
c  2  so  38.295926                    $ 12 inches hydraulic fluid
c  1  so   9.847450                    $ 12000 gram Pu sphere
c  2  so  12.387450                    $  1 inch   hydraulic fluid
c  2  so  40.327450                    $ 12 inches hydraulic fluid
   1  so  11.272517                    $ 18000 gram Pu sphere
   2  so  13.812517                    $  1 inch   hydraulic fluid
c  2  so  41.752517                    $ 12 inches hydraulic fluid
c  1  so  12.407010                    $ 24000 gram Pu sphere
c  2  so  14.947010                    $  1 inch   hydraulic fluid
c  2  so  42.887010                    $ 12 inches hydraulic fluid
c  1  so  13.365046                    $ 30000 gram Pu sphere
c  2  so  15.905046                    $  1 inch   hydraulic fluid
c  2  so  43.845046                    $ 12 inches hydraulic fluid
c  1  so  14.202481                    $ 36000 gram Pu sphere
c  2  so  16.742481                    $  1 inch   hydraulic fluid
c  2  so  44.682481                    $ 12 inches hydraulic fluid
c  1  so  14.951329                    $ 42000 gram Pu sphere
c  2  so  17.491329                    $  1 inch   hydraulic fluid
c  2  so  45.431329                    $ 12 inches hydraulic fluid
c  1  so  15.631853                    $ 48000 gram Pu sphere
c  2  so  18.171853                    $  1 inch   hydraulic fluid
c  2  so  46.111853                    $ 12 inches hydraulic fluid
c  1  so  16.257782                    $ 54000 gram Pu sphere
c  2  so  18.797782                    $  1 inch   hydraulic fluid
c  2  so  46.737782                    $ 12 inches hydraulic fluid
c  1  so  16.838903                    $ 60000 gram Pu sphere
c  2  so  19.378903                    $  1 inch   hydraulic fluid
c  2  so  47.318903                    $ 12 inches hydraulic fluid
   3  so  99.000000                    $ outside world

mode n
tmp     2.585e-6     2r               $ 001 - 003    300K everywhere
        1j                            $ outside world
kcode  24000   1.0   50  550
ksrc    0.00    0.00    0.00
m1    1001.50c   -0.015131            $ Plutonium hydraulic fluid sphere
      6000.50c   -0.167617
      8016.50c   -0.044169
     15031.50c   -0.021377
     94239.55c   -0.751707
mt1  lwtr.01t                         $ 300 K = 27 C = 80.6 F
m2    1001.50c   -0.060939            $ hydraulic fluid
      6000.50c   -0.675075
      8016.50c   -0.177890
     15031.50c   -0.086096
mt2  lwtr.01t                         $ 300 K = 27 C = 80.6 F
m3    8016.50c    0.20                $ Air
      7014.50c    0.80
totnu
ctme  14480.
print   30 40 60 110 126 140 170
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Criticality Curves for Plutonium Hydraulic Fluid Mixtures
HNF-33756, Rev. 0

These hydraulic fluid MCNP results for FYRQUEL® 220 are for 0 wt% ^{240}Pu "00", the first third "RB" is for bare reflection geometry, the second third "RF" are for 12 inch hydraulic fluid reflection, and the final third, "RN" are for 1 inch hydraulic fluid reflection. The concentration in grams per liter is given before the "m", "00002" is for 2 grams plutonium per liter. The mass in grams plutonium is given after the "m", "08000" is for 8,000 grams plutonium in the sphere.

Case Designation	k_{eff}	$\pm\sigma_{calc}$
hyoil00RB00002m04000	0.74941	0.00009
hyoil00RB00002m16000	0.80112	0.00008
hyoil00RB00002m28000	0.81249	0.00006
hyoil00RB00002m40000	0.81778	0.00006
hyoil00RB00002m52000	0.82105	0.00006
hyoil00RB00002m64000	0.82356	0.00006
hyoil00RB00002m76000	0.82513	0.00007
hyoil00RB00002m88000	0.82629	0.00007
hyoil00RB00002mAA000	0.82748	0.00006
hyoil00RB00002mBB000	0.82844	0.00006
hyoil00RB00003m13000	0.95864	0.00010
hyoil00RB00003m16000	0.96644	0.00009
hyoil00RB00003m19000	0.97216	0.00009
hyoil00RB00003m22000	0.97622	0.00009
hyoil00RB00003m25000	0.97979	0.00008
hyoil00RB00003m28000	0.98286	0.00009
hyoil00RB00003m31000	0.98496	0.00008
hyoil00RB00003m34000	0.98682	0.00008
hyoil00RB00003m37000	0.98902	0.00007
hyoil00RB00003m40000	0.99013	0.00008
hyoil00RB00005m00300	0.59444	0.00017
hyoil00RB00005m00600	0.75075	0.00019
hyoil00RB00005m00900	0.83203	0.00018
hyoil00RB00005m01200	0.88454	0.00018
hyoil00RB00005m01500	0.92197	0.00017
hyoil00RB00005m01800	0.95034	0.00015
hyoil00RB00005m02100	0.97226	0.00016
hyoil00RB00005m02400	0.99027	0.00016
hyoil00RB00005m02700	1.00587	0.00016
hyoil00RB00005m03000	1.01851	0.00015
hyoil00RB00010m00400	0.67272	0.00022
hyoil00RB00010m00675	0.81434	0.00023
hyoil00RB00010m00950	0.90076	0.00023
hyoil00RB00010m01225	0.96170	0.00022
hyoil00RB00010m01500	1.00720	0.00024
hyoil00RB00010m01775	1.04265	0.00023
hyoil00RB00010m02050	1.07183	0.00021
hyoil00RB00010m02325	1.09599	0.00021
hyoil00RB00010m02600	1.11615	0.00022
hyoil00RB00010m02875	1.13419	0.00019
hyoil00RB00020m00350	0.56792	0.00024
hyoil00RB00020m00650	0.75347	0.00025
hyoil00RB00020m00950	0.86563	0.00024
hyoil00RB00020m01250	0.94275	0.00027
hyoil00RB00020m01550	1.00078	0.00026
hyoil00RB00020m01850	1.04752	0.00026
hyoil00RB00020m02150	1.08473	0.00026
hyoil00RB00020m02450	1.11513	0.00025
hyoil00RB00020m02750	1.14254	0.00024
hyoil00RB00020m03050	1.16509	0.00025
hyoil00RB00030m00300	0.46056	0.00021
hyoil00RB00030m00670	0.70089	0.00025
hyoil00RB00030m01040	0.83480	0.00026
hyoil00RB00030m01410	0.92555	0.00027
hyoil00RB00030m01780	0.99276	0.00027
hyoil00RB00030m02150	1.04418	0.00026
hyoil00RB00030m02520	1.08667	0.00028
hyoil00RB00030m02890	1.12141	0.00027
hyoil00RB00030m03260	1.15065	0.00027
hyoil00RB00030m03630	1.17670	0.00026
hyoil00RB00050m00700	0.61381	0.00026
hyoil00RB00050m01200	0.78102	0.00027
hyoil00RB00050m01700	0.88879	0.00027
hyoil00RB00050m02200	0.96592	0.00028
hyoil00RB00050m02700	1.02405	0.00028
hyoil00RB00050m03200	1.07232	0.00027
hyoil00RB00050m03700	1.11132	0.00027
hyoil00RB00050m04200	1.14466	0.00028
hyoil00RB00050m04700	1.17389	0.00028
hyoil00RB00050m05200	1.19850	0.00026
hyoil00RB00075m00800	0.56517	0.00025
hyoil00RB00075m01500	0.75959	0.00028
hyoil00RB00075m02200	0.87855	0.00028
hyoil00RB00075m02900	0.96248	0.00028
hyoil00RB00075m03600	1.02563	0.00030
hyoil00RB00075m04300	1.07586	0.00030
hyoil00RB00075m05000	1.11739	0.00028
hyoil00RB00075m05700	1.15235	0.00026
hyoil00RB00075m06400	1.18227	0.00028
hyoil00RB00075m07100	1.20782	0.00030
hyoil00RB00100m01500	0.69006	0.00027
hyoil00RB00100m02400	0.83719	0.00028
hyoil00RB00100m03300	0.93438	0.00029
hyoil00RB00100m04200	1.00757	0.00029
hyoil00RB00100m05100	1.06383	0.00028
hyoil00RB00100m06000	1.10890	0.00027
hyoil00RB00100m06900	1.14675	0.00027
hyoil00RB00100m07800	1.17863	0.00026
hyoil00RB00100m08700	1.20548	0.00027
hyoil00RB00100m09600	1.23096	0.00028
hyoil00RB00200m02000	0.60891	0.00025
hyoil00RB00200m03600	0.78967	0.00028
hyoil00RB00200m05200	0.90376	0.00030
hyoil00RB00200m06800	0.98513	0.00028
hyoil00RB00200m08400	1.04719	0.00029
hyoil00RB00200m10000	1.09713	0.00028
hyoil00RB00200m11600	1.13770	0.00027
hyoil00RB00200m13200	1.17282	0.00029
hyoil00RB00200m14800	1.20261	0.00030
hyoil00RB00200m16400	1.22871	0.00029
hyoil00RB00300m03000	0.63345	0.00028
hyoil00RB00300m05100	0.79620	0.00028
hyoil00RB00300m07200	0.90322	0.00028
hyoil00RB00300m09300	0.98139	0.00028
hyoil00RB00300m11400	1.04116	0.00029
hyoil00RB00300m13500	1.09028	0.00030
hyoil00RB00300m15600	1.13046	0.00029

hyoil00RB00300m17700	1.16452	0.00030
hyoil00RB00300m19800	1.19443	0.00029
hyoil00RB00300m21900	1.21993	0.00028
hyoil00RB00500m04000	0.60410	0.00025
hyoil00RB00500m07000	0.77315	0.00028
hyoil00RB00500m10000	0.88315	0.00028
hyoil00RB00500m13000	0.96354	0.00028
hyoil00RB00500m16000	1.02568	0.00029
hyoil00RB00500m19000	1.07563	0.00028
hyoil00RB00500m22000	1.11762	0.00029
hyoil00RB00500m25000	1.15311	0.00030
hyoil00RB00500m28000	1.18388	0.00028
hyoil00RB00500m31000	1.21075	0.00029
hyoil00RB01000m05500	0.56629	0.00026
hyoil00RB01000m10000	0.74070	0.00025
hyoil00RB01000m14500	0.85427	0.00028
hyoil00RB01000m19000	0.93749	0.00029
hyoil00RB01000m23500	1.00243	0.00029
hyoil00RB01000m28000	1.05477	0.00028
hyoil00RB01000m32500	1.09867	0.00029
hyoil00RB01000m37000	1.13585	0.00029
hyoil00RB01000m41500	1.16825	0.00028
hyoil00RB01000m46000	1.19710	0.00029
hyoil00RB02000m06000	0.50874	0.00022
hyoil00RB02000m12000	0.69680	0.00024
hyoil00RB02000m18000	0.81846	0.00026
hyoil00RB02000m24000	0.90665	0.00027
hyoil00RB02000m30000	0.97544	0.00028
hyoil00RB02000m36000	1.03161	0.00028
hyoil00RB02000m42000	1.07865	0.00028
hyoil00RB02000m48000	1.11913	0.00028
hyoil00RB02000m54000	1.15376	0.00028
hyoil00RB02000m60000	1.18448	0.00028
hyoil00RB03000m06000	0.49369	0.00018
hyoil00RB03000m12000	0.67040	0.00022
hyoil00RB03000m18000	0.78772	0.00023
hyoil00RB03000m24000	0.87464	0.00026
hyoil00RB03000m30000	0.94364	0.00026
hyoil00RB03000m36000	1.00009	0.00028
hyoil00RB03000m42000	1.04787	0.00027
hyoil00RB03000m48000	1.08947	0.00028
hyoil00RB03000m54000	1.12620	0.00028
hyoil00RB03000m60000	1.15763	0.00029
hyoil00RB05000m05000	0.47803	0.00015
hyoil00RB05000m10000	0.63516	0.00019
hyoil00RB05000m15000	0.74254	0.00020
hyoil00RB05000m20000	0.82465	0.00021
hyoil00RB05000m25000	0.89130	0.00023
hyoil00RB05000m30000	0.94752	0.00024
hyoil00RB05000m35000	0.99502	0.00025
hyoil00RB05000m40000	1.03683	0.00024
hyoil00RB05000m45000	1.07413	0.00025
hyoil00RB05000m50000	1.10789	0.00027
hyoil00RB10000m06500	0.64938	0.00013
hyoil00RB10000m09000	0.72587	0.00014
hyoil00RB10000m11500	0.78779	0.00015
hyoil00RB10000m14000	0.84045	0.00016
hyoil00RB10000m16500	0.88604	0.00018
hyoil00RB10000m19000	0.92720	0.00018
hyoil00RB10000m21500	0.96351	0.00018
hyoil00RB10000m24000	0.99641	0.00021
hyoil00RB10000m26500	1.02750	0.00020

hyoil00RB10000m29000	1.05518	0.00019
hyoil00RB15000m04500	0.68699	0.00013
hyoil00RB15000m06000	0.75219	0.00013
hyoil00RB15000m07500	0.80648	0.00014
hyoil00RB15000m09000	0.85337	0.00015
hyoil00RB15000m10500	0.89425	0.00015
hyoil00RB15000m12000	0.93094	0.00017
hyoil00RB15000m13500	0.96406	0.00017
hyoil00RB15000m15000	0.99519	0.00018
hyoil00RB15000m16500	1.02294	0.00017
hyoil00RB15000m18000	1.04906	0.00017
hyoil00RB19600m03000	0.69227	0.00012
hyoil00RB19600m04000	0.75572	0.00013
hyoil00RB19600m05000	0.80863	0.00014
hyoil00RB19600m06000	0.85401	0.00015
hyoil00RB19600m07000	0.89353	0.00015
hyoil00RB19600m08000	0.92916	0.00015
hyoil00RB19600m09000	0.96203	0.00015
hyoil00RB19600m10000	0.99157	0.00017
hyoil00RB19600m11000	1.01876	0.00018
hyoil00RB19600m12000	1.04401	0.00018
hyoil00RF00002m04000	0.76032	0.00009
hyoil00RF00002m16000	0.80439	0.00007
hyoil00RF00002m28000	0.81425	0.00006
hyoil00RF00002m40000	0.81951	0.00007
hyoil00RF00002m52000	0.82218	0.00006
hyoil00RF00002m64000	0.82450	0.00006
hyoil00RF00002m76000	0.82608	0.00006
hyoil00RF00002m88000	0.82701	0.00006
hyoil00RF00002mAA000	0.82812	0.00007
hyoil00RF00002mBB000	0.82919	0.00007
hyoil00RF00003m13000	0.96531	0.00009
hyoil00RF00003m16000	0.97181	0.00008
hyoil00RF00003m19000	0.97647	0.00008
hyoil00RF00003m22000	0.98053	0.00008
hyoil00RF00003m25000	0.98363	0.00008
hyoil00RF00003m28000	0.98572	0.00007
hyoil00RF00003m31000	0.98833	0.00007
hyoil00RF00003m34000	0.98955	0.00008
hyoil00RF00003m37000	0.99139	0.00007
hyoil00RF00003m40000	0.99266	0.00007
hyoil00RF00005m00300	0.71389	0.00017
hyoil00RF00005m00600	0.84158	0.00016
hyoil00RF00005m00900	0.90652	0.00016
hyoil00RF00005m01200	0.94797	0.00014
hyoil00RF00005m01500	0.97746	0.00015
hyoil00RF00005m01800	0.99947	0.00015
hyoil00RF00005m02100	1.01700	0.00015
hyoil00RF00005m02400	1.03144	0.00014
hyoil00RF00005m02700	1.04370	0.00014
hyoil00RF00005m03000	1.05366	0.00014
hyoil00RF00010m00400	0.82925	0.00021
hyoil00RF00010m00675	0.94659	0.00020
hyoil00RF00010m00950	1.01535	0.00020
hyoil00RF00010m01225	1.06327	0.00019
hyoil00RF00010m01500	1.09863	0.00019
hyoil00RF00010m01775	1.12647	0.00019
hyoil00RF00010m02050	1.14817	0.00019
hyoil00RF00010m02325	1.16745	0.00018
hyoil00RF00010m02600	1.18342	0.00017
hyoil00RF00010m02875	1.19689	0.00017
hyoil00RF00020m00350	0.77057	0.00023

hyoil00RF00020m00650	0.93353	0.00024
hyoil00RF00020m00950	1.02527	0.00023
hyoil00RF00020m01250	1.08765	0.00023
hyoil00RF00020m01550	1.13331	0.00022
hyoil00RF00020m01850	1.16893	0.00023
hyoil00RF00020m02150	1.19799	0.00021
hyoil00RF00020m02450	1.22161	0.00021
hyoil00RF00020m02750	1.24192	0.00021
hyoil00RF00020m03050	1.26029	0.00022
hyoil00RF00030m00300	0.67939	0.00024
hyoil00RF00030m00670	0.90184	0.00023
hyoil00RF00030m01040	1.01640	0.00024
hyoil00RF00030m01410	1.08902	0.00024
hyoil00RF00030m01780	1.14214	0.00023
hyoil00RF00030m02150	1.18252	0.00023
hyoil00RF00030m02520	1.21530	0.00024
hyoil00RF00030m02890	1.24264	0.00024
hyoil00RF00030m03260	1.26419	0.00022
hyoil00RF00030m03630	1.28452	0.00022
hyoil00RF00050m00700	0.83644	0.00026
hyoil00RF00050m01200	0.98385	0.00026
hyoil00RF00050m01700	1.07327	0.00025
hyoil00RF00050m02200	1.13543	0.00024
hyoil00RF00050m02700	1.18215	0.00025
hyoil00RF00050m03200	1.21963	0.00025
hyoil00RF00050m03700	1.24974	0.00024
hyoil00RF00050m04200	1.27456	0.00023
hyoil00RF00050m04700	1.29662	0.00023
hyoil00RF00050m05200	1.31584	0.00024
hyoil00RF00075m00800	0.79681	0.00024
hyoil00RF00075m01500	0.97220	0.00026
hyoil00RF00075m02200	1.07245	0.00024
hyoil00RF00075m02900	1.14018	0.00026
hyoil00RF00075m03600	1.19070	0.00026
hyoil00RF00075m04300	1.23069	0.00024
hyoil00RF00075m05000	1.26252	0.00026
hyoil00RF00075m05700	1.28886	0.00026
hyoil00RF00075m06400	1.31157	0.00025
hyoil00RF00075m07100	1.33129	0.00025
hyoil00RF00100m01500	0.91452	0.00026
hyoil00RF00100m02400	1.04149	0.00026
hyoil00RF00100m03300	1.12181	0.00025
hyoil00RF00100m04200	1.17987	0.00025
hyoil00RF00100m05100	1.22365	0.00025
hyoil00RF00100m06000	1.25924	0.00024
hyoil00RF00100m06900	1.28840	0.00026
hyoil00RF00100m07800	1.31293	0.00024
hyoil00RF00100m08700	1.33462	0.00023
hyoil00RF00100m09600	1.35249	0.00024
hyoil00RF00200m02000	0.84336	0.00025
hyoil00RF00200m03600	1.00628	0.00028
hyoil00RF00200m05200	1.10232	0.00027
hyoil00RF00200m06800	1.16925	0.00026
hyoil00RF00200m08400	1.21848	0.00026
hyoil00RF00200m10000	1.25677	0.00026
hyoil00RF00200m11600	1.28970	0.00026
hyoil00RF00200m13200	1.31606	0.00024
hyoil00RF00200m14800	1.33878	0.00025
hyoil00RF00200m16400	1.35875	0.00025
hyoil00RF00300m03000	0.86739	0.00026
hyoil00RF00300m05100	1.01443	0.00027
hyoil00RF00300m07200	1.10462	0.00026
hyoil00RF00300m09300	1.16852	0.00026
hyoil00RF00300m11400	1.21731	0.00026
hyoil00RF00300m13500	1.25470	0.00027
hyoil00RF00300m15600	1.28657	0.00027
hyoil00RF00300m17700	1.31308	0.00025
hyoil00RF00300m19800	1.33585	0.00025
hyoil00RF00300m21900	1.35662	0.00024
hyoil00RF00500m04000	0.83834	0.00026
hyoil00RF00500m07000	0.99560	0.00027
hyoil00RF00500m10000	1.09080	0.00027
hyoil00RF00500m13000	1.15763	0.00027
hyoil00RF00500m16000	1.20842	0.00025
hyoil00RF00500m19000	1.24825	0.00026
hyoil00RF00500m22000	1.28152	0.00026
hyoil00RF00500m25000	1.30840	0.00025
hyoil00RF00500m28000	1.33340	0.00025
hyoil00RF00500m31000	1.35370	0.00025
hyoil00RF01000m05500	0.79525	0.00027
hyoil00RF01000m10000	0.96581	0.00027
hyoil00RF01000m14500	1.06841	0.00027
hyoil00RF01000m19000	1.13997	0.00028
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hyoil00RF01000m28000	1.23764	0.00027
hyoil00RF01000m32500	1.27353	0.00028
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hyoil00RF02000m06000	0.71933	0.00025
hyoil00RF02000m12000	0.91804	0.00027
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hyoil00RF02000m24000	1.11603	0.00028
hyoil00RF02000m30000	1.17703	0.00028
hyoil00RF02000m36000	1.22559	0.00027
hyoil00RF02000m42000	1.26546	0.00027
hyoil00RF02000m48000	1.29896	0.00027
hyoil00RF02000m54000	1.32827	0.00028
hyoil00RF02000m60000	1.35390	0.00026
hyoil00RF03000m06000	0.68401	0.00023
hyoil00RF03000m12000	0.88153	0.00027
hyoil00RF03000m18000	1.00012	0.00026
hyoil00RF03000m24000	1.08484	0.00027
hyoil00RF03000m30000	1.14874	0.00028
hyoil00RF03000m36000	1.20067	0.00029
hyoil00RF03000m42000	1.24342	0.00027
hyoil00RF03000m48000	1.27905	0.00027
hyoil00RF03000m54000	1.31053	0.00027
hyoil00RF03000m60000	1.33829	0.00027
hyoil00RF05000m05000	0.62849	0.00019
hyoil00RF05000m10000	0.81737	0.00023
hyoil00RF05000m15000	0.93641	0.00023
hyoil00RF05000m20000	1.02337	0.00025
hyoil00RF05000m25000	1.09083	0.00026
hyoil00RF05000m30000	1.14632	0.00027
hyoil00RF05000m35000	1.19277	0.00025
hyoil00RF05000m40000	1.23226	0.00026
hyoil00RF05000m45000	1.26735	0.00026
hyoil00RF05000m50000	1.29857	0.00026
hyoil00RF10000m06500	0.77323	0.00018
hyoil00RF10000m09000	0.86391	0.00018
hyoil00RF10000m11500	0.93626	0.00021
hyoil00RF10000m14000	0.99598	0.00022
hyoil00RF10000m16500	1.04720	0.00021

hyoil00RF10000m19000	1.09229	0.00022
hyoil00RF10000m21500	1.13193	0.00024
hyoil00RF10000m24000	1.16723	0.00023
hyoil00RF10000m26500	1.19934	0.00023
hyoil00RF10000m29000	1.22965	0.00024
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hyoil00RF15000m06000	0.85401	0.00017
hyoil00RF15000m07500	0.91757	0.00018
hyoil00RF15000m09000	0.97138	0.00018
hyoil00RF15000m10500	1.01827	0.00019
hyoil00RF15000m12000	1.06049	0.00020
hyoil00RF15000m13500	1.09788	0.00020
hyoil00RF15000m15000	1.13242	0.00021
hyoil00RF15000m16500	1.16346	0.00021
hyoil00RF15000m18000	1.19272	0.00021
hyoil00RF19600m03000	0.76164	0.00015
hyoil00RF19600m04000	0.83454	0.00015
hyoil00RF19600m05000	0.89536	0.00017
hyoil00RF19600m06000	0.94675	0.00017
hyoil00RF19600m07000	0.99223	0.00017
hyoil00RF19600m08000	1.03258	0.00018
hyoil00RF19600m09000	1.06935	0.00020
hyoil00RF19600m10000	1.10252	0.00019
hyoil00RF19600m11000	1.13312	0.00018
hyoil00RF19600m12000	1.16157	0.00020
hyoil00RN00002m04000	0.75285	0.00009
hyoil00RN00002m16000	0.80167	0.00007
hyoil00RN00002m28000	0.81285	0.00007
hyoil00RN00002m40000	0.81831	0.00006
hyoil00RN00002m52000	0.82163	0.00006
hyoil00RN00002m64000	0.82373	0.00006
hyoil00RN00002m76000	0.82494	0.00006
hyoil00RN00002m88000	0.82693	0.00007
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hyoil00RN00002mBB000	0.82854	0.00007
hyoil00RN00003m13000	0.96034	0.00009
hyoil00RN00003m16000	0.96777	0.00009
hyoil00RN00003m19000	0.97304	0.00009
hyoil00RN00003m22000	0.97728	0.00008
hyoil00RN00003m25000	0.98081	0.00008
hyoil00RN00003m28000	0.98377	0.00008
hyoil00RN00003m31000	0.98605	0.00007
hyoil00RN00003m34000	0.98781	0.00008
hyoil00RN00003m37000	0.98951	0.00008
hyoil00RN00003m40000	0.99106	0.00007
hyoil00RN00005m00300	0.63122	0.00018
hyoil00RN00005m00600	0.77750	0.00018
hyoil00RN00005m00900	0.85374	0.00017
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hyoil00RN00005m01500	0.93755	0.00016
hyoil00RN00005m01800	0.96405	0.00016
hyoil00RN00005m02100	0.98495	0.00016
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hyoil00RN00010m00400	0.72003	0.00023
hyoil00RN00010m00675	0.85330	0.00022
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hyoil00RN00010m01500	1.03275	0.00022
hyoil00RN00010m01775	1.06578	0.00022
hyoil00RN00010m02050	1.09240	0.00021

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hyoil00RN00020m00350	0.63125	0.00024
hyoil00RN00020m00650	0.80712	0.00024
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hyoil00RN00020m01250	0.98452	0.00026
hyoil00RN00020m01550	1.03842	0.00024
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hyoil00RN10000m16500	0.93997	0.00020
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hyoil00RN19600m07000	0.93453	0.00017
hyoil00RN19600m08000	0.97164	0.00017
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